Residence time of tagged magnetic particle in an internal-loop airlift reactor with an enlarged dual separator

Jaroslav KLEIN, António A. VICENTE and José A. TEIXEIRA

Centro de Engenharia Biológica – IBQF, Departamento de Engenharia Biológica, Universidade do Minho, Campus de Gualtar, 4710-057 Braga, Portugal

The internal-loop airlift reactor with an enlarged separator zone belongs to promising multiphase contactors for chemical and biotechnological processes, where an intimate contact of all three phases (gas-liquid-solid) is required. In view of separator design, internal-loop airlift reactors are conventionally divided into the ALRs without separator (when the separator diameter is equal to the diameter of the outer column – $D_{SEP} = D_C$) and the ALRs with separator ($D_{SEP} > D_C$) [1]. In the ALR reactor with an enlarged head zone, different separator configurations can be obtained by adjusting the length of the draft tube. Thus, two basic constructions of the ALR are considered, depending on whether the upper edge of the draft tube is situated in enlarged or in narrow part of the separator zone (see Figure A). The first configuration is named the ALR with simple enlarged separator and in the second case ALR with "dual" separator. Its duality lies in the fact that although such a reactor configuration belongs to the group of the ALR with separator (according to the conventional terminology), in view of the bubble separation efficiency, this is in fact the ALR without separator.

An airlift reactor (ALR) with an enlarged dual separator, seldom referred in literature, may provide an efficient retention of both solid particles (in enlarged part of separator) and gas bubbles (in narrow part) inside the reactor making such a type of reactor particularly attractive for continuous high cell density biosystems [2]. By using a tagged particle and knowing its behaviour (RTD, velocity in all reactor sections, etc.), essential information on reactor design, hydrodynamics and mixing can be obtained.

The main goal of this study was to utilize a hydrodynamic measuring technique suggested for application in a high cell density multiphase system to obtain information on the residence time of the tagged particle in all reactor sections independently of each other (riser, downcomer and separator). Different lengths of draft tube and liquid levels in the separator were tested to show how the dual separator acting as the degassing and sedimentation zone affects hydrodynamic performance of two-phase internal-loop airlift reactor.

Experimental

A 50 L internal-loop airlift reactor with an enlarged degassing zone (442 mm in diameter) was used for hydrodynamic measurements (see Figure A). The diameter ratio of head zone to outer column was 3.1. A riser to downcomer cross-sectional area ratio (A_D/A_R) was 1.2 and a liquid level above the draft tube (H_T) varied from 90 and 480 mm. A tracer method with a magnetic particle (with high magnetic permeability) as a flowfollower was used [3]. The calibration procedure showed that the experimental data on residence time of the particle could be simply used for determining the liquid circulation velocity, if the accurate value of the particle velocity is known. The density of the magnetic particle was adjusted to be very close to that of the liquid medium. The effect of the design of the enlarged separator (height of draft tube H_{DT} and liquid level in the head zone H_T) was investigated.

Results

Effect of liquid level H_T

It is worth to notice that a modification of liquid level in the enlarged head zone does not change only the liquid volume for bubble separation but also the design of the separator zone. The liquid level in the separator zone H_T had a negative effect on the riser holdup and mainly on the downcomer holdup and a positive influence on liquid

circulation. However, as the level of the gas-liquid dispersion reached the enlarged part of separator, H_T had not any significant effect on ALR hydrodynamics.

Effect of separator design (H_{DT})

The modification of the separator design as a consequence of change of height of the draft tube strongly affected primarily the bubble-separation efficiency and by this means the reactor hydrodynamics (Figure B). While the dual separator zone ensures high downcomer and total gas holdup inside the ALR already at low gas flow rates, the reactor set with the longest draft tube separates perfectly the bubbles in the head zone even at the highest gas flow rates. Thus, increase of height of the draft tube generates faster net liquid circulation due to the increase of a driving force.

RTD of tagged particle

On the base of histograms of the residence time of the tagged particle in the dual separator zone and visual observations, three flow patterns of the particle in the separator zone were found. In the first, the particle is entrained by the prevailing liquid flow directly into the downcomer corresponding to the most frequent bin of the lowest RTD values. The second flow pattern of the particle is determined by its presence in turbulent narrow part of separator zone, just above the top of the draft tube. The last flow pattern is represented by the highest RTD values corresponding to the particle residence in the upper enlarged zone of separator. If the values of the total circulation time (t_C) corresponding only to the direct 180° turn of the tagged particle from the riser to downcomer were extracted, almost identical values of t_C independently of the liquid level in the separator (H_T) used were found. This also suggests that the large scatter of original t_C values is mainly caused by fluctuations of the liquid flow in the separator zone.

Intensity of turbulence (RMS)

The measuring technique allows comfortable collection of a statistically sufficient amount of data on liquid velocity. The calculated standard deviation of velocity can be used to assess an intensity of turbulence in all important parts of airlift, characterised by RMS number (root mean square). Evaluation of the results showed that as the H_{DT} increased the intensity of turbulence in both the downcomer and riser zones decreased. This effect was more pronounced in the downcomer part, where the decrease of amount of bubbles was stronger with increase H_{DT}, implying that the presence of the gas bubbles substantially contributes to the intensity of fluid turbulence.

Conclusion

The measuring tagging technique using the flowfollower allowed the acquisition of various important information on the multiphase flow and distribution of gas and solid phases in the ALR. The hydrodynamics of the ALR was found to be affected by all design parameters. The results of experiments with different heights of draft tube demonstrated how easily various operating flow patterns can be achieved ranging from typical flow patterns for an internal-loop ALR with high downcomer gas holdup to those of an external-loop with low or nil gas holdup. The results of this study enable a reasonable estimation of suitable hydrodynamic conditions in the multiphase contactor.

Acknowledgement

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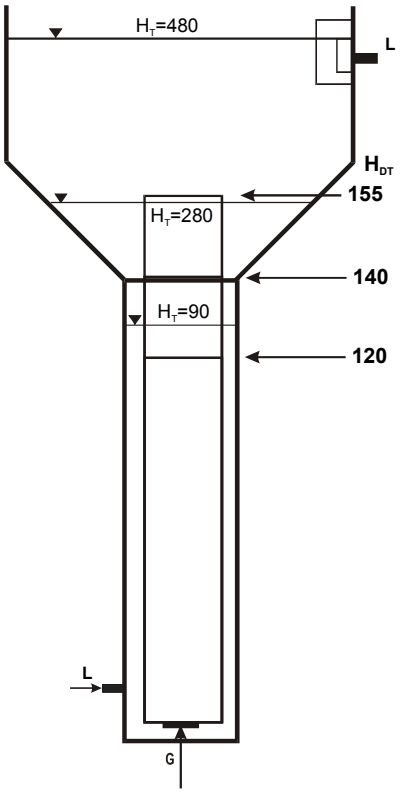
Figure. A. Gas holdup in the riser and downcomer sections and liquid velocity in the riser V_{LR} as a function of gas superficial velocity. Parameter of lines is the height of draft tube H_{DT}. B. Scheme of airlift reactor used in experiments with different liquid levels H_T and height of draft tube H_{DT}.



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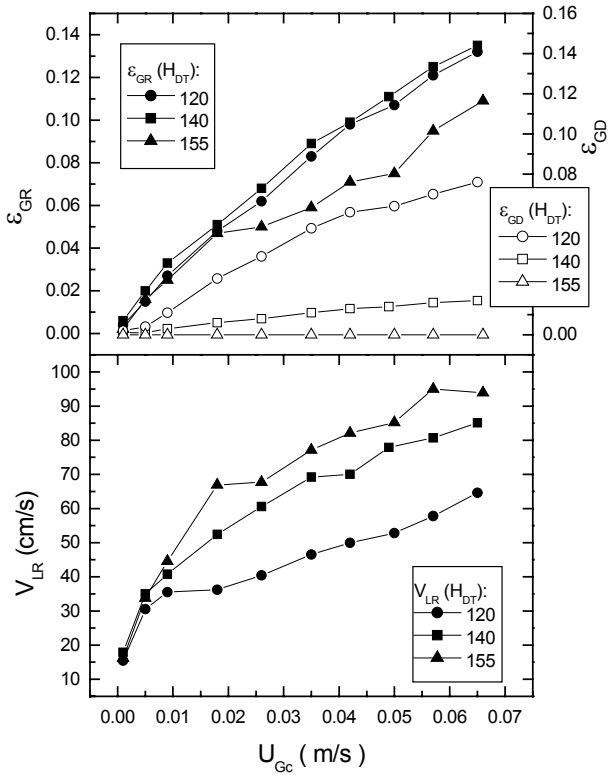

B.